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SUSPENDED SOLIDS IN LIQUID EFFLUENTS: A LITERATURE SURVEY

by

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ABSTRACT

An international literature review and telephone mail survey was conducted with respect to technical and regulatory aspects of suspended solids in radioactive liquid wastes from nuclear power stations. Results of the survey are summarized and show that suspended solids are an important component of some waste streams. The data available, while limited, show these solids to be associated largely with corrosion products. The solids are highly variable in quantity, size and composition. Filtration is commonly applied for their removal from liquid effluents and is effective. Complex interactions with receiving waters can result in physical/chemical changes of released radionuclides and these phenomena have been seen as reason for not applying regulatory controls based on suspended solids content.

RÉSUMÉ

Une étude de la documentation internationale et un sondage par téléphone et courrier ont été exécutés concernant les aspects techniques et réglementaires des solides en suspension dans les déchets radioactifs liquides des centrales nucléaires. Les résultats de l'étude sont résumés et montrent que les solides en suspension représentent un élément important de certains écoulements de déchets. Malgré leur nombre limité, les données disponibles indiquent que ces solides sont en grande partie associés avec des produits de corrosion et qu'ils varient beaucoup en quantité, en dimension et en composition. La filtration est une méthode efficace souvent utilisée pour les extraire des effluents liquides. Des réactions complexes avec les eaux réceptives peuvent provoquer des changements physiques ou chimiques, ou les deux, des radionucléides dégagés. Ces phénomènes expliquent pourquoi aucun contrôle réglementaire n'a été effectué d'après le contenu des solides en suspension.

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Executive Summary

An international non-Canadian survey of the published scientific and technical literature, was conducted and supplemented by a letter and telephone survey of nuclear utilities and regulatory agencies around the world. The material received consisting of over 300 published papers and responses from twenty countries was synthesized to provide a core of technical data with respect to the origin, nature, character and amount of suspended solids contained in routine low level radioactive liquid wastes released from nuclear power stations. Other aspects examined included the treatments for removal of these materials, their fate in the environment once released and the regulatory policy of national authorities with regard to control of suspended solids in liquid wastes.

Radioactive suspended solids were found to originate from floor and equipment drains and decontamination streams from controlled areas of the plants.

They contain:

(a) discrete particulate radionuclides

(b) non-radioactive particulates which are made active by adsorption of radioactive species.

Depending on the type of reactor systems, some particulate associated fission products were identified but the majority of suspended solid radionuclides appear to be corrosion or activation products. Depending on the radionuclides involved, most of the radioactivity in a liquid waste stream may be associated with suspended solids. Limited information was found with respect to the particle size quantity and composition of these although some data exists for component streams such as equipment drains and laundry drains. The relevance of this data as representative of liquid effluents in general is not clear from the papers reviewed. The treatments employed for the removal of these solids from liquid effluent streams include stream segregation, filtration, ion exchange and volume reduction by evaporation. More sophisticated technologies may be applied however it is clear that filtration for removal of suspended solids content is a priority treatment internationally.

The fate of suspended solids after release to the environment was found to be both simple and complex. Materials in solid form report to the sediments as expected, however, some released radionuclides do not remain in solid

form nor do some soluble radionuclides remain in solution. Interactions between the receiving water and the discharged liquid effluents can result in the formation of new radioactive solids by attachment or by complex formation.

The regulatory control of liquid releases by the national authorities does not in general encompass direct monitoring or control of suspended solids content. The requirement to limit the total activity of these liquids combined with the fact that most of the radioactivity in the effluent is associated with these suspended solids provides sufficient incentive that filtration is commonly applied.

Post-release physiochemical changes are cited by some national authorities as the major reason for avoiding controls based on suspended solids content.

Further work is recommended to reconcile international information with Canadian data, determine the contribution from various sources and evaluate the significance of environmental pathways for radionuclides which are associated with suspended solids.

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1. Introduction

The purpose of this study was to compile and systematically analyze the available international literature with respect to the presence of suspended solid materials in nuclear power plant liquid effluents.

Because Atomic Energy Control Board (AECB) staff were in the process of conducting their own survey of their licensees, the present study scope was intended to exclude Canadian data.

Two approaches were specified in the terms of reference for the work;

1. A survey of international published literature

2. A telephone/letter survey of international utilities and regulatory agencies

Two aspects of the question were to be addressed;

1. Regulatory aspects of control of suspended solids in nuclear power plant effluents

2. Technical aspects including, origin, quantity, nature, treatment and fate of suspended solids when released to the natural environment.

1.1 Background

The term "suspended solids" has a variety of definitions which are both broad and specific and can be applied to suspended solids in an effluent stream or to suspended solids present in the water column of a receiving water.

A general definition is given by the American Society for the Testing of Materials (ASTM) standard D-3977-80 as;

> "Sediment that is carried in suspension by the turbulent component of water or by Brownian movement."

A procedure for determining its concentration is given which specifies filtration on a 0.45 micron millipore filter. Standard Methods for the Examination of Water and Wastewater (1982) specifies a similar procedure (224C).

The Chemical Rubber Company Handbook of Chemistry and Physics 66th Edition provides a definition of a colloid as follows;

> "In general, particles of colloidal dimensions are approximately 10 Angstroms (A) to 1 micron (u) in size."

and

> "A phase dispersed to such a degree that the surface forces become an important factor in determining its properties."

The particle diameter considered to be in suspension is any size greater than 1 micron with the upper limit being determined only by fluid flow conditions.

The practical significance of defining a suspended solid arises from the fact that particle size is almost universally the criteria which determines the effectiveness of treatment for suspended solids removal, as well as the rate of settling of suspended particulates in water under quiescent conditions. Some jurisdictions "define" suspended solids on the basis of filter pore size which can range from 0.5 to 25 microns. That is, the filtrate is defined as containing no suspended solid material.

Perhaps most importantly for this study, it is the particle size of suspended radioactive materials which determines the degree to which these materials follow the laws of solubility and dispersion upon being released to a receiving water body.

1.2 Glossary of Terms

The following terms are used either in the text or in the references.

Suspended solid	- Any solid particle of diameter greater than about 1 micron capable of being settled or filtered from its liquid medium.
Suspended particulate	- Same as suspended solid.
Insolubles	- Same as suspended solid.
Crud	- Same as suspended solid but generally applied to residues of tanks or resevoirs.
Sediment	- Can have the same meaning as suspended solid or crud but term is also applied to small diameter, usually mobile particles of stream, lake or ocean bottom.
Mud	- Same meaning as suspended solid, crud or sediment.
Bottoms	- Same as suspended solid but usually applied to residues of tanks.
Seston	- Same meaning as suspended solid but usually used in reference to naturally occurring particles suspended in river, lake or ocean.
Speciation	- The differentiation of radionuclides into two or more physical or chemical forms as insoluble, soluble, neutral charge, positive charge or negative charge.

1.3 Cautionary Note

Luykx and Fraser of the Health and Safety Directorate of the Commission of the European Communities provide a cautionary overview with respect to the intercomparability of data on radioactive effluent discharges. They state in the conclusions to their 1978 IAEA report. (Ref. 6)

> "...data as published at present usually reflect.. what is necessary to satisfy the limits imposed by the competent authorities in the discharge authorization. The authorities will--have already considered all the variables--and having explicitly or implicitly defined "negligible" made themselves conversant with the information necessary to interpret the discharge data. The terms of the authorization, however, are usually written quite justifiably with operational convenience in mind. The simplifications introduced for this purpose lead to sensibly disparate methods of expressing firstly the limitations in terms of activity, and subsequently the discharge data".

For this reason, although it may be tempting to compare international discharge data, the reader is advised not to do so without a more complete understanding of the numerical values than is undertaken for this study.

2. Literature Survey

Based on a predefined keyword search strategy, a series of seven (7) relevant technical databases available in Canada through the National Research Council's CANOLE search system, and four (4) U.S. databases accessible on the DIALOG search system were screened using in-house computer links.

Two U.S. Department of Energy databases which are not accessible directly in Canada were searched using the USDOE search service at Oak Ridge, Tennessee.

Databases examined included the following;

CAN/OLE

NTIS	- National Technical Information Service
INIS	- International Nuclear Information System
EPD	- Electric Power Database - EPRI
CAC	- Chemical Abstracts (2 Databases)
EI	- Engineering Index
EIM	- Engineering Meetings
ELIAS	- Environment Canada

DIALOG (US)

WRA	- Water Resources Abstracts
PA	- Pollution Abstracts
EVB(File 65)	- Environmental Bibliography
File 40	- Enviroline

US DOE

RECON/EDB	- Energy Data Base
STN	- International Search Service

In addition, several manual literature searches were undertaken at the University of New Brunswick Library. These included the Envirofiche files and the Energyfiche files.

Two databases, the National Technical Information System (NTIS), and the International Nuclear Information System (INIS) provided the majority of information relative to the subject area of interest.

In total more than 300 abstracts were reviewed. Thirty-three references provided most of the relevant data.

Using the most applicable and recent literature, telephone contacts were made and/or letters were written to the principal authors requesting copies of studies or background data.

Inquiries to principle authors yielded a number of study reports which included:

- Four Radiological Surveillance Studies conducted by the United States Environmental Protection Agency (USEPA) in the early to mid 1970's. (Ref. 1, 2, 3, 4)

- A compilation of Selected Marine Ecological Data by the Sandia National Laboratory printed in July, 1986. (Ref. 23)

- A report dealing with exposure models prepared by the National Radiological Protection Board dated November, 1980. (Ref. 29)

All other material was received either as abstract listings or complete papers extracted from proceedings, journals or books, the largest quantity being from proceedings of the International Atomic Energy Agency (IAEA). Certain key papers are included in appendices to this report and in some cases, extracts are included in the text. The collected papers and reports have been catalogued and retained for future reference.

The literature survey is presented by country in the following subsections. The analysis and summary of the data is the subject of Section 4 of this report.

Wherever possible the source documents have been included in the appendices, however some material presented is obtained from documents which are too large to be included. In these cases only the title page has been appended.

2.1 United States of America

United States Environmental Protection Agency (USEPA) studies dated 1970, 1971, 1974 and 1976 conducted at Dresdan (BWR fresh water site, Illinois River), Yankee Rowe (PWR fresh water site, Sherman Reservoir) Haddam Neck (Connecticut Yankee), (PWR fresh water site Connecticut River) and Oyster Creek (BWR brackish water site, Barnegat Bay), provided the most comprehensive block of U.S. data with respect to suspended solids in liquid effluents from nuclear power plants. (Ref. 1, 2, 3, 4)

The 1976 Oyster Creek study provides an overview of the treatment practise generally employed for U.S. direct water cooled nuclear power plants. This includes segregation of wastes into four categories;

1 - High Conductivity Wastes (Floor drains),

2 - Chemical Wastes (Laboratory and decontamination, and demineralizer regeneration),

3 - Low Conductivity Wastes (Demineralized wastes),

4 - Laundry Wastes.

High conductivity and chemical wastes are evaporated with the condensate going to low conductivity waste, collector tanks. From here these three streams along with the laundry wastes are processed through a precoat type waste collector filter and a mixed bed demineralizer before discharge to the cooling water.

Treatment systems at other U.S. nuclear power plants studied appear to be similar.

Even after treatment, some radionuclides, in particular, Mn-54 and Co-60 occurred largely in particulate form in the effluent waste tanks (74% and 52% retained on 0.45 micron membrane filter respectively).

Following discharge of the waste tanks, some radionuclides remained in the insoluble form. Sixty to one hundred percent of Cr-51, Mn-54 and Co-60 inventory was found to be associated with particles collected by filtration of cooling canal water after discharge dilution.

Data from Table 1 provides a good overview of a typical filtered and unfiltered high conductivity liquid waste stream. Note the significant differences between filtered (no parentheses) and unfiltered (parentheses) specific activities for the activation products Co-58 and Co-60.

Table 1 (Table 3.1, Ref. 1)

Radionuclide Concentrations in High-conductivity Liquid Waste, pCi/ml*

Radionuclide	Nov. 12, 1967	Jan. 13, 1968	March 18, 1968	June 25, 1968	Aug. 20, 1968	Average
^{3}H	900** (NM)	950 (NM)	520 (NM)	770 (NM)	1,100 (NM)	850
^{54}Mn	NM (< 1)**	NM (< 1)	NM (< 1)	NM (< 1)	< 1 (22)	(4)
^{55}Fe	NM (NM)	NM (NM)	NM (NM)	NM (45)	NM (50)	(48)
^{58}Co	NM (65)	4 (34)	880 (1,800)	3 (85)	18 (260)	230 (450)
^{60}Co	NM (33)	1 (46)	500 (1,350)	4 (180	11(1,400)	130 (600)
^{89}Sr	NM (140)	220 (320)	140 (170)	85 (89)	24 (34)	120 (150)
^{90}Sr†	NM (14)	12 (17)	30 (30)	8 (9)	9 (11)	15 (16)
^{91}Y	NM (66)	1 (26)	NM (< 1)	NM (1)	NM (< 1)	(19)
^{131}I	NM (5)	8 (6)	NM (45)	46 (49)	15 (15)	22 (24)
^{134}Cs	NM (9)	7 (10)	80 (90)	47 (50)	27 (34)	40 (39)
^{137}Cs	NM (29)	35 (35)	150 (170)	140(180)	99 (103)	106 (99)
^{140}Ba†	NM (45)	40 (180)	65 (95)	22 (54)	35 (105)	41 (92)
^{144}Ce	NM (5)	NM (< 1)	NM (< 1)	NM (< 1)	8 (16)	(4)
beta‡	NM (540)	440(1,040)	1,600 (NM)	NM (550)	140 (NM)	
alpha‡	NM (< 0.1)	NM (< 0.1)	NM (NM)	NM (NM)	NM (NM)	

*concentration of radionuclides at indicated date of sampling; 1 pCi/ml = 1 x 10^{-6} μCi/ml.

**values without parentheses are for filtered solution, values in parentheses for unfiltered solution.

†solutions also contained ^{90}Y at concentrations equal to its ^{90}Sr parent; and ^{140}La at concentrations 1.15 times those of its ^{140}Ba parent.

‡gross radioactivity measured approximately 1 week after sample collection and not corrected for decay.

NM: not measured; < values are 3 σ counting error.

The 1970 study at Dresdan makes reference to the attachment of some radionuclides to suspended material in the cooling water discharge canal, in particular, Co-60 and Cs-137. The latter radionuclide is referred to as being "entirely soluble" in the waste tank and "probably retained partially in silt suspended in coolant canal water".

The effect of pH of the process cooling water is addressed in the 1971 USEPA study. The following table, extracted from this study, shows the difference in radionuclide content of "crud" samples of October 4, 1968 when the pH of cooling water was approximately 5, and of July 10, 1969 when the pH was about 9. The ratios are only qualitative as indicated by ratios that exceed unity since concentrations are average monthly values. Nevertheless it is apparent that the pH of the process stream can have a measurable effect on the quantity of the listed radionuclides which are generated as insolubles in that stream. It is worth noting that for this power plant, the pH of coolant water is controlled by the addition of boric acid to control neutron flux during part of the annual operating cycle.

Table 2

		October 4, 1968	
Radionuclide		in crud, uCi/ml	crud/total
^{51}Cr	pH-5	1.1×10^{-4}	0.13
^{54}Mn		5.3×10^{-6}	0.01
^{59}Fe		1.3×10^{-5}	0.07
^{58}Co		2.7×10^{-5}	0.08
^{60}Co		1.2×10^{-5}	0.13
^{110m}Ag		7.8×10^{-6}	0.41
		July 10, 1969	
Radionuclide		in crud, uCi/ml	crud/total
^{51}Cr	pH-9	3.2×10^{-4}	1.5
^{54}Mn		2.8×10^{-4}	1.2
^{59}Fe		1.8×10^{-4}	2.0
^{58}Co		1.6×10^{-3}	1.6
^{60}Co		5.5×10^{-4}	4.2
^{110m}Ag		1.2×10^{-6}	<1.2

Extracted from Ref. 2, page 16.

The USEPA Oyster Creek study, dated 1976, also addresses the issue of insoluble radionuclides. Table 3 presents the physical/chemical states of five major radionuclides in the liquid waste tank after treatment. Mn-54 and Co-60 are seen to be the major particulate radionuclides and all have some component of particulate form (i.e. are retained on 0.45 micron millipore filters).

Table 3 (Table 4.3, Ref. 4)

Chemical States of Radionuclides in Liquid Waste Sample Tank, Sept. 25, 1972.

Radionuclide	Percent retained in each separation: Membrane filter, 0.45u-pore size	Cation-exchange resin, Dowex-50	Anion-exchange resin, Dowex-1	Residue
^{54}Mn	74	26	0	0
^{60}Co	52	48	0	0
^{131}I	9	8	75	8
^{134}Cs	3	97	0	0
^{137}Cs	3	97	0	0
		Solvent extract CCl_4	Precipitation, AgI	
^{131}I	12	23	59	6

Notes:

1. Solution was neutral.
2. Order of treatment is from left to right.
3. 50 ml solution passed through resins in columns each 8-cm long, 1.2-cm diameter, at 1 ml/min flow rate.
4. 50 ml solution equilibrated with 50 ml CCl_4, then mixed with 24 mg NaI and excess $AgNO_3$.

Table 4 effectively presents the percent of measured radionuclide concentration which can be retained on filters after discharge into cooling canal.

Table 4 (Table 4.15, Ref. 4)

Radionuclides	Percent of measured concentration Retained on filters			
	Jan. 18, 1972	May 16, 1972	Sept. 25 1972	July 17, 1973
^{51}Cr*	---	86 ±30	---	100±20
^{54}Mn	>60	81 ± 8	88±20	99 ± 5
^{60}Co	70± 20	88± 5	84±12	97 ± 5
^{134}Cs	---	41± 4	4± 2	<15
^{137}Cs	---	46± 5	3± 1	< 5

*Filtrate was not analyzed for Cr-51; the predicted concentration was used instead of the total measured concentration.

With regard to Table 4 the report concludes;

> "The high particulate concentration of some radionuclides in the coolant canal is evident from the data presented in Table 4-15 From 60 to 100 percent of the Cr-51, Co-54 were associated with particles collected by filtration. The low retention of Cs-134 and Cs-137 by filtration was similar to that observed in liquid from the waste sample tank (see Table 4.3). On May 16, 1972, however, 41 and 46 percent, respectively, were associated with particles during a discharge from the laundry drain tank, which may have had a higher fraction of particulate radiocesium than the liquids from the waste sample tank. In general, the fractions of Mn-54 and Co-60 associated with particles in the circulating coolant water are significantly higher than that observed in liquids from the waste sample tank (see Table 4.3). This would indicate the formation of, or adsorption on, particulate matter in the coolant canal after release. Other radionuclides retained efficiently by filtration were Nb-95, Zr-95, Ba-140, Ce-141, and Ce-144.
>
> The coolant canal measurements and tracer studies provided an excellent opportunity to develop and verify

techniques for monitoring selected radionuclides discharged by the station to a seawater environment. It was apparent from the variable distribution of radionuclides between particulate and dissolved species that monitoring techniques in the aqueous environment of nuclear power stations should be tested under actual conditions to ensure that all physico-chemical species are collected. The concentrations of major radionuclides in the coolant canal were between 0.1 and 10 pCi/l during waste discharge and generally consistent with predicted values. The coolant canal studies showed that monitoring waste discharges after dilution was difficult because of low concentrations and recirculation effects. The advantages and validity of predicting radionuclide concentrations discharged to Barnegat Bay by analysis of the liquid waste before dilution and application of the calculated dilution factor were shown.

The observation that several radionuclides in the coolant canal were mostly particulate suggests that realistic predictions of radionuclide levels in aquatic organisms based on effluent concentrations would require additional information regarding the physicochemical species of these radionuclides in seawater."

In an extensive sediment sampling and analysis program in Barnegat Bay, Cobalt 60 was found to be the most widely distributed radionuclide attributable to the Oyster Creek Station. Concentration of Co-60 in sediments ranged from 0.26 to 18.6 pCi/g in the discharge canal. The report suggests that sorption of Co-60 and Mn-54 likely occurs on very fine particles shortly after mixing and that these particles are transported with the moving water until they settle out. (Ref. 4)

Table 5 presents the analysis obtained during the study.

Although pathways for soluble Co-60 and Mn-54 are identified, the suspended solids contribution is not discussed.

Adsorption and desorption of these radionuclides on sediment, is suggested and is identified as an area of future work.

Table 5.29 Radionuclide Analyses of Oyster Creek Sediment Samples, pCi/g Dry Weight

Sample No.	Site	Dry Density	^{40}K	^{54}Mn	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{226}Ra	^{232}Th
					October 18-21, 1971					
1	1	0.91	7.1 ± 0.3	0.75 ± 0.14	4.9 ± 0.1	0.24 ± 0.07	<0.05	0.87 ± 0.03	2.4 ± 0.3	0.42 ± 0.08
2	2	1.71	0.8 ± 0.1	<0.09	0.26 ± 0.02	<0.05	<0.02	0.02 ± 0.01	0.8 ± 0.2	0.21 ± 0.04
3	3	1.35	1.9 ± 0.2	<0.17	0.82 ± 0.04	<0.07	<0.03	0.05 ± 0.01	1.2 ± 0.2	0.34 ± 0.04
4	4	1.15	8.4 ± 0.4	0.38 ± 0.15	4.2 ± 0.1	<0.12	<0.05	0.28 ± 0.02	1.6 ± 0.3	0.55 ± 0.10
5	5	1.20	9.7 ± 0.4	1.7 ± 0.2	9.0 ± 0.1	0.22 ± 0.08	<0.06	0.53 ± 0.03	1.6 ± 0.3	0.60 ± 0.10
6	6	0.97	13.7 ± 0.5	0.68 ± 0.19	5.0 ± 0.1	<0.14	<0.06	0.61 ± 0.03	2.1 ± 0.3	0.70 ± 0.10
10	10	0.88	16.0 ± 1.1	3.6 ± 0.3	18.6 ± 0.4	<0.26	<0.14	1.3 ± 0.1	1.9 ± 0.6	0.90 ± 0.40
11	11	1.01	16.1 ± 0.5	<0.26	1.2 ± 0.1	<0.12	<0.05	0.15 ± 0.02	2.3 ± 0.3	0.70 ± 0.10
12	12	1.00	14.6 ± 0.5	0.95 ± 0.19	5.0 ± 0.1	<0.18	<0.06	0.36 ± 0.03	1.8 ± 0.3	0.70 ± 0.10
13	13	1.39	5.0 ± 0.3	<0.18	5.3 ± 0.1	<0.08	<0.05	0.10 ± 0.01	1.4 ± 0.2	0.43 ± 0.06
17	17	1.24	12.6 ± 0.4	<0.11	0.10 ± 0.03	<0.06	<0.03	0.14 ± 0.02	1.0 ± 0.3	0.46 ± 0.05
18	18	1.16	13.1 ± 0.4	<0.21	0.19 ± 0.03	0.13 ± 0.04	<0.03	0.46 ± 0.02	1.7 ± 0.3	0.53 ± 0.06
19	19	1.71	2.1 ± 0.2	<0.12	<0.04	<0.04	<0.03	<0.01	0.6 ± 0.2	0.09 ± 0.01
20	20	1.54	1.0 ± 0.3	0.05 ± 0.02	0.23 ± 0.03	<0.06	<0.02	0.05 ± 0.01	0.5 ± 0.1	0.22 ± 0.05
21	21	1.36	5.7 ± 0.3	<0.11	0.61 ± 0.03	<0.04	<0.04	0.11 ± 0.02	1.4 ± 0.3	0.46 ± 0.06
22	22	1.24	5.9 ± 0.3	<0.09	0.10 ± 0.02	<0.07	<0.03	0.16 ± 0.02	1.3 ± 0.3	0.37 ± 0.05
23	23	1.39	5.2 ± 0.3	<0.03	0.13 ± 0.02	<0.05	<0.02	0.13 ± 0.02	0.3 ± 0.1	0.41 ± 0.05
24	24	1.59	0.6 ± 0.1	<0.04	0.04 ± 0.01	<0.03	<0.01	<0.01	0.3 ± 0.2	0.10 ± 0.03
25	25	1.12	14.5 ± 0.5	<0.12	0.37 ± 0.04	<0.09	<0.12	0.33 ± 0.02	1.7 ± 0.3	0.62 ± 0.07
26	26	1.49	7.3 ± 0.3	<0.09	0.09 ± 0.02	<0.07	<0.04	0.03 ± 0.01	1.4 ± 0.3	0.62 ± 0.06
27	27	0.99	14.8 ± 0.5	0.34 ± 0.13	1.6 ± 0.1	<0.11	<0.04	0.34 ± 0.03	1.9 ± 0.4	0.68 ± 0.09
28	28	1.30	4.1 ± 0.2	<0.08	0.09 ± 0.02	<0.06	<0.04	0.10 ± 0.01	1.3 ± 0.3	0.28 ± 0.05
29	29	1.22	14.0 ± 0.4	<0.12	0.54 ± 0.04	<0.09	<0.03	0.21 ± 0.02	1.6 ± 0.3	0.63 ± 0.07
30	30	1.17	13.7 ± 0.4	<0.16	0.04 ± 0.02	0.12 ± 0.05	<0.03	0.33 ± 0.02	1.8 ± 0.2	0.61 ± 0.07
31	31	1.38	12.0 ± 0.4	<0.10	0.23 ± 0.3	<0.07	<0.03	0.07 ± 0.02	1.7 ± 0.3	0.76 ± 0.07
32	32	1.19	14.0 ± 0.4	<0.10	0.14 ± 0.03	<0.09	<0.03	0.22 ± 0.02	2.1 ± 0.4	0.77 ± 0.07
33	33	1.58	3.2 ± 0.2	<0.08	0.23 ± 0.02	<0.05	<0.02	0.05 ± 0.01	0.9 ± 0.2	0.24 ± 0.03
34	34	1.01	14.4 ± 0.4	<0.18	1.00 ± 0.05	0.14 ± 0.04	<0.04	0.31 ± 0.03	2.0 ± 0.4	0.62 ± 0.07
35	35	0.97	8.5 ± 0.4	<0.18	1.7 ± 0.1	<0.10	<0.04	0.30 ± 0.03	2.4 ± 0.4	0.68 ± 0.06
36	36	1.22	1.9 ± 0.1	<0.06	0.03 ± 0.01	<0.06	<0.02	0.13 ± 0.02	1.2 ± 0.3	0.24 ± 0.03
					April 17-18, 1972					
100	40	1.15	17.2 ± 0.6	<0.04	<0.04	0.14 ± 0.04	<0.02	0.45 ± 0.03	1.2 ± 0.1	0.72 ± 0.08
101	4	1.04	13.6 ± 0.6	0.15 ± 0.03	0.85 ± 0.06	0.09 ± 0.05	<0.03	0.32 ± 0.03	0.8 ± 0.1	0.70 ± 0.10
104	5	0.88	9.5 ± 0.5	0.91 ± 0.06	7.6 ± 0.1	0.17 ± 0.07	<0.04	0.53 ± 0.04	1.0 ± 0.2	0.50 ± 0.10

In a 1976 study by Harrison, Wong and Heft of Lawrence Livermore Laboratory, the investigators examined the "Interactions of Radionuclides in Water, Particulates, and Oysters in the Discharge Canal of a Nuclear Power Plant". (Ref. 5)

> "Oysters introduced into the discharge canal rapidly accumulated the released radionuclides. Our results indicate that suspended particulates play an important role in the accumulation of some radionuclides detected in the oysters generally reflected in the levels measured in the water and particulates.---
>
> For Mn-54, Co-60 and Zn-65 the concentration factors calculated for the oysters from the expected water concentrations were higher than those predicted for the corresponding stable elements. This apparent discrepancy occurs because the calculated "expected concentrations" of radionuclides in the water do not accurately represent the concentrations available to the oysters. The calculations do not take into account the binding of the radionuclides to particulate matter which increases their residence time in the discharge canal relative to the residence time of the water."

These conclusions are supported by the work of Preston, in the Blackwater Estuary (U.K.) for Zn-65. (Ref. 7)

2.2 United Kingdom

Mitchell et al, in a paper presented in 1980, discuss the implications of sediment contamination from liquid discharges at the Windscale fuel reprocessing plant. While the similarities to suspended solids released from nuclear power station effluents do not exist in terms of release quantities, or radionuclides, the behaviour of the radionuclides in the receiving water environment is similar. After the primary pathway of Ru-106 and Ce-144 via the Porphyra to Laverbread to man, the authors state; (Ref. 8)

> "A second important pathway involves external exposure due to contamination of the foreshore, especially areas where mud and fine silt collect, the critical nuclides being the gamma-emitters zirconium-95/niobium-95 and ruthenium-106. Basic radiological control monitoring consists of regular gamma dose-rate surveys, especially concentrating on those areas where the dose-rate is highest (a nearby river estuary), and like the previous pathway, this pathway has been the subject of extensive research."

Considerable work has been undertaken by the U.K. Ministry of Agriculture, Fisheries and Food (MAFF) with respect to the liquid discharges at British Nuclear Fuels Ltd. (BNFL) fuel reprocessing plant at Sellafield in Cumbria.

Again, while the data is not specific to nuclear power plant effluents, the considerable volume of material by Penreath, Harvey, Lovett et al (Ref. 9) provide interesting and potentially useful information for assessing the fate of released soluble and particulate radionuclides. It is apparent, for example, that certain released radionuclides undergo changes in chemical form after release and that the various oxidation states exhibit differences in their absorptive properties and biological availabilities depending on pH and other receiving water characteristics. While this work was largely focused on plutonium, neptunium and other transuranics, the same principles may well apply to the lighter radionuclides of interest in nuclear power plant effluents.

The Bradwell power station of the Central Electricity Generating Board, (CEGB) has been the subject of several studies by MAFF (Ref. 8, 25). In general these studies are more pathways oriented than source oriented, however the data provides a good appreciation for the variation in critical radionuclide which occurs over time whether from changes in operating conditions or improved understanding of the critical pathways.

2.3 Sweden

Devell et al of Studsvik Energiteknik AB, Nykoping, Sweden in a 1980 paper to the IAEA presented data from several Swedish nuclear power stations. They arrive at a number of conclusions with respect to the presence of suspended material in effluents as follows; (Ref. 10)

> "Annual release figures for the different sites are listed in Table II, giving total releases for the categories total alpha, total beta/gamma and tritium. The list of nuclides identified is given in Table III, as well as the maximum annual releases of each nuclide. The discharges of alphaemitting nuclides are very low. Among beta/gamma emitters Cr-51, Co-58, Co-60, Zn-65, Cs-134 and Cs-137 are found in the highest concentrations. Total releases of beta/gamma from the nuclear power plants reached a maximum during 1976-1977 but have decreased since then. At Oskarshamn, for example, the decrease is due to improved removal of suspended material in the effluents, and replacement of brass tubes in the condenser with ones of titanium, which reduced the production of Zn-65. As usual, tritium is discharged to a lesser extent from BWR's than from PWR's. The tritium releases from Studsvik are one order of magnitude higher than from a PWR. In general, the fraction of suspended material is determined by analysing the effluents but this is not shown in the tables. This fraction governs sedimentation in the local area outside the plant. Sedimentation behaviour is under study; some aspects of this are given in section 8."

Some evaluation of the effect of suspended solids on sediment load is provided for radiocesium.

> "A preliminary analysis shows that about 1% of the Cs-137 released at Studsvik is found in sediments of the 20 km^2 bay outside the release point. This is in fair agreement with analysis of the properties of liquid effluents with regard to the fraction of suspended material.
>
> Sedimentation and dispersion outside the Oskarshamn nuclear power plant have been studied by a group from the National Swedish Environment Protection Board (11). Studies around the Barseback nuclear power plant have been carried out by groups from the University of Lund and Riso Research Establishment. It would be advantageous to include the experimental results from those groups in our further studies to improve the dose calculation model and the relevant parameter data."

2.4 Finland

Sjoblom and Ojala of the Institute for Radiation Protection in Helsinki, Finland in a 1980 paper to the IAEA, present liquid effluent discharge data for the Loviisa nuclear power plant; (Ref. 11)

> "The model does not take into consideration the fact that the discharge nuclides may leave the water phase by sedimentation and different adsorption or absorption phenomena. These are connected with the physico-chemical state of radionuclides in the discharge water and the changes that occur when the discharge becomes mixed with sea water. According to Holmberg (3) Co-60 and Mn-54 in Swedish conditions existed both in cationic and particulate form in the waste water tanks of a nuclear power plant, and Ag-110m in anionic or particulate form. Preston (4) showed that the Co-60 and Mn-54 in liquid discharges from Bradwell power station were mostly in particulate form and Sb-124 in soluble form. The distribution of discharge contents into soluble and particulate form was studied by Ilus et al (5) in connection with discharge from a waste tank which had been stored for more than one year at the Loviisa power plant. Antimony 124 was almost completely in soluble form, Mn-54 in particulate form, and Co-58, Co-60 and Ag-110m in both soluble and particulate form. After mixing with the sea water circuit Sb-124 was still in soluble form and Ag-110m in both soluble and particulate form.
>
> When comparing the activation concentrations calculated with the spreading model and measured in the environmental samples it can be seen, in agreement with other studies, that Sb-124 seems to remain in the water phase longer than other discharge nuclides. The authors have also detected Sb-124 in sea water samples more often then other discharge nuclides."

2.5 Norway

B. Rygg, Norsk Institutt for Vannforkning, Oslo January, 1974, (Ref. 12) evaluated the radioecological effect of released liquid effluents and concluded;

> "The state of a given element (physicochemical) is of great importance for the concentration factor. The uptake is reduced when the element is bound in colloidal form or as particulate matter. For animals that filter the water (blue mussel for example), the uptake of the nuclide will be great if it occurs as

particulate matter. In plant plankton the elements are taken up largely only as smaller molecules in solution but change into the bound state in particulate matter after having been taken up."

2.6 Commission of the European Communities

Two papers from the International Symposium on the Behavior of Long-lived Radionuclides in the Marine Environment (September, 1983, La Spezia, Italy) provide some insights into the mechanisms of adsorption, transport and uptake of particulate associated radionuclides.

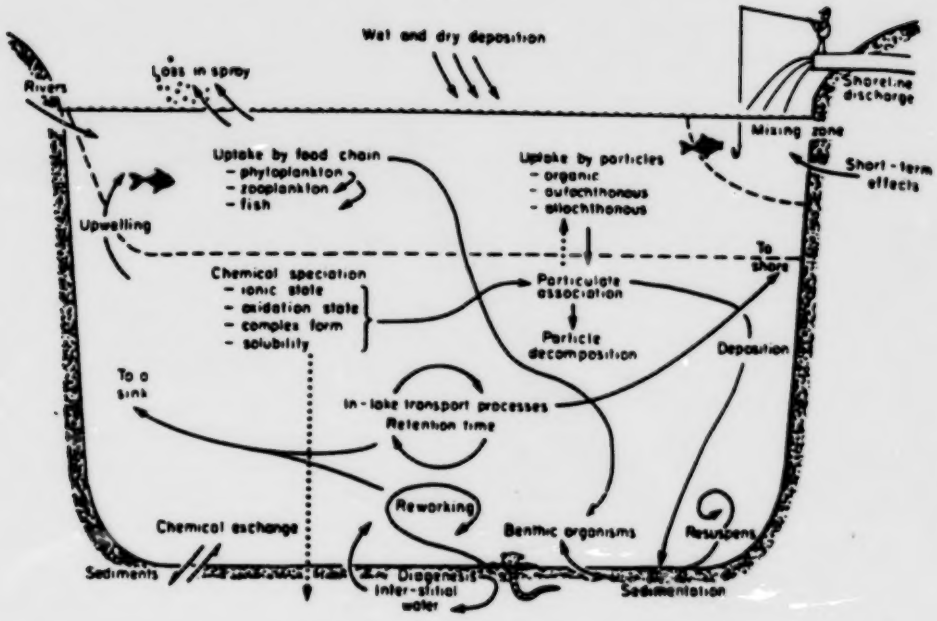
While some of the data presented is experimental and the concern is with long-lived radionuclides, the mechanisms of attachment to particulate matter and in particular the attachment to biotic particulate matter are germane to the subject of this review.

The abstract of a paper by Thomas H. Sibley, Laboratory of Radiation Ecology, University of Washington, Seattle, Washington, U.S.A. entitled, "Comparative Adsorption of Selected Radionuclides on Different Types of Suspended Particulates" will illustrate the point. (Ref. 13)

> "The eventual fate of long-lived radionuclides in the marine environment is determined by their partitioning between soluble and particulate phases and their distribution among different types of particulates. Adsorption to organic particulates, for example, may introduce radionuclides into marine food chains. Results of adsorption, desorption and dialysis experiments are presented for several different isotopes. All radionuclides adsorb to suspended particulates. However, the extent of adsorption depends upon the radionuclide and specific particulates in the experiment. In constant shaking experiments most radionuclides adsorb more strongly to natural marine sediments than to the clay mineral, calcium montmorillinite or detritus. However, in dialysis experiments some isotopes appear to have greater affinity for detritus and phytoplankton which suggests that these elements may be transported with organic particulates."

David N. Edgington of the Center for Great Lakes Studies, University of Wisconsin, Milwaukee and Donald M. Nelson Environmental Research Division, Argonne National Laboratory, in a lengthy paper entitled "The Chemical Behavior of Long-lived Radionuclides in the Marine Environment" discuss the complexity of physical/chemical radionuclide interactions in receiving waters and illustrate the point with a figure.

Figure 1 (Fig. 7, Ref. 14)



2.7 Organisation For Economic Cooperation and Development

The proceedings of a 1979 conference on management of power reactor wastes (Ref. 31) contains three presentations dealing with the sources, characteristics and treatment of suspended solids in liquid effluents.

Condensate demineralizer backwash water is identified as a major contributor to suspended solids (crud) content of equipment drains according to two Japanese studies (Ref. 31, 33) and particle size distributions are provided as shown in Figures 2, 3. A French study describes electromagnetic filtration technology.

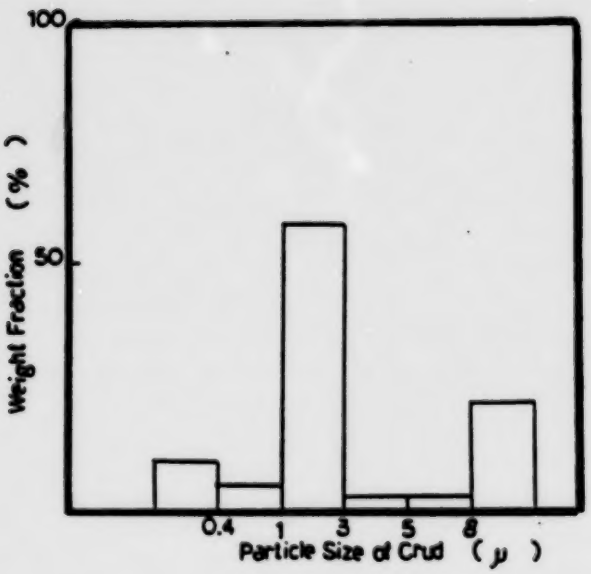


Figure 2 (Fig. 2 Ref. 31)

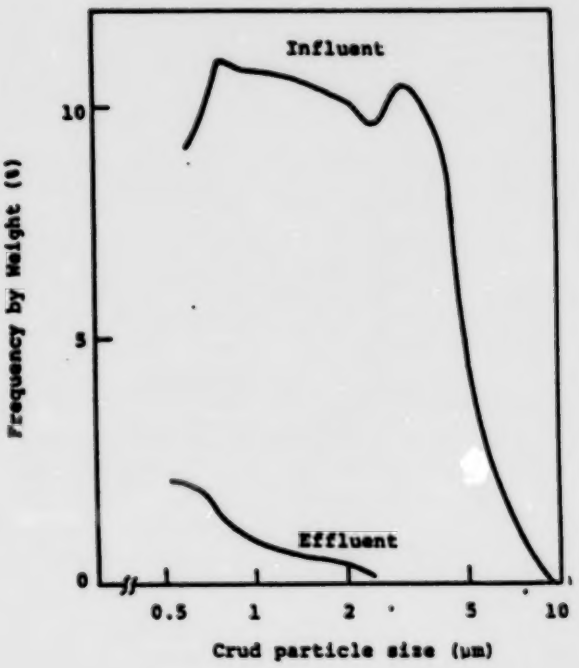


Figure 3 (Fig. 2 Ref. 33)

Three techniques for suspended solids removal from liquid effluents are described in detail;

1. Nucleopore Membrane Filter (NPMF)

2. Electromagnetic Filtration

3. Centrifugal Clarification

The first and third discussions are refinements of known technologies for application to a reactor operating environment Electromagnetic Filtration is a developing technology which has been applied to prevent suspended solids, mainly corrosion products, from entering areas of high neutron flux thereby reducing their specific activities as well as the magnitude of the suspended solids problem. The electromagnetic filtration technique is shown to be particularly effective in trapping metallic radionuclides such as Co-60, Mn-54, Cr-51 and Fe-59.

3. Utility/Regulatory Agency Survey

A form letter was drafted for mailing to international utilities and regulatory agencies.

A mailing list of one hundred and sixty three (163) utilities and regulatory agencies in forty (40) countries known or believed to have operating nuclear power plants was compiled, based on the 1983/84 International Directory of Nuclear Utilities and the Nuclear Canada Yearbook.

The letters were prepared in English and French and mailed in September 1986. They included fifty six (56) U.S. nuclear utilities.

Twenty (20) replies were received from this solicitation representing sixteen (16) countries. One (1) U.S. utility responded and the U.S. Nuclear Regulatory Commission was contacted directly and provided useful data.

Replies to the letter survey have been summarized and tabulated by country in Table 6 following this section.

In all, thirty seven (37) English language and three (3) French language regulatory agency letters were sent, and one hundred and seven (107) English language and two (2) French language utility letters. Follow up letters were sent where the responding party recommended alternate names or organizations who should be contacted.

Copies of the mailing lists and form letters have been provided in Appendix C to this report.

Letter/Telephone Survey

Telephone calls and letters to individuals or organizations were sent as follow up where it was considered these might provide additional data. This resulted in contacts with:

The U.S. Nuclear Regulatory Commission
The U.S. Environmental Protection Agency
The Savannah River Radioecology Laboratory (U.S.)
The IAEA Laboratory of Marine Radioactivity (Monaco)
The National Radiological Protection Board (U.K.)
The Water Pollution Control Federation (U.S.)
National Nuclear Corporation Limited (U.K.)
Universite Catholique de Louvain (Belgium)
Battelle Pacific Northwest Laboratories (U.S.)
Sandia National Laboratories (U.S.)

For simplicity, the material obtained from the above sources has been considered with the literature survey. The following section deals with replies from utilities and regulatory agencies.

3.1 United States

3.1.1 United States Nuclear Regulatory Commission

Regulatory control of radioactive nuclear power plant liquid effluents in the U.S. is provided through 10CFR-20 article 106, Chapter 1. (Appendix B) (Ref. 16)

With regard to the United States regulatory position on suspended solids, Mr. R.E. Alexander, Chief, Safety Research Application Branch, Division of Regulatory Applications, Office of Nuclear Regulatory Research, United States Nuclear Regulatory Commission responded in a letter on Oct. 20, 1986;

> "Our regulations do not require specific monitoring for suspended solids in effluents. One reason for this is that the physio-chemical form of the material changes with time and distance from the point of release. Extensive studies of these changes have been made by the Battelle Pacific Northwest Laboratory (under NRC and DOE sponsorship) and by the Environmental Protection Agency."

Further details of sampling and monitoring guidelines to licensees were kindly provided in the form of USNRC Regulatory Guide 1.21.

Mr. Alexander was contacted by telephone and suggested we speak to Mr. Hal Peterson in his office who might provide additional technical details.

Mr. Peterson was contacted, and he confirmed that, based on studies in the Columbia River in the late 1960's and later work by the USEPA in the early to mid 1970's, the USNRC had adopted the position that direct monitoring of the suspended solids component of liquid effluent discharges was not a practical regulatory mechanism. He provided a 1970 paper in support of this approach. (Ref. 15)

It should be noted that the USNRC approach does not mean that suspended solids in U.S. nuclear power plant effluents are not controlled. In fact, considerable filtration and treatment is necessary to meet the requirements of 10CFR-20 including a requirement to measure suspended solids content of effluents where limits specified are to be exceeded.

3.1.2 U.S. Utilities

Although fifty six (56) U.S. nuclear utilities were canvassed, only one (1) reply was received. The single reply did not provide any data with respect to suspended solids in liquid effluents.

3.2 United Kingdom

3.2.1 United Kingdom Atomic Energy Agency

The United Kingdom Atomic Energy Agency (UKAEA) and in particular the Harwell Laboratory responded that the primary concern for liquid effluents from nuclear power stations rests with the Central Electricity Generating Board, (CEGB) although there are a number of non-CEGB generating sites in the U.K. which are controlled by other operators.

Licensing of nuclear power plants in the U.K. falls under the Nuclear Installations Act and the Nuclear Installations Inspectorate who have responsibility for storage of radioactive (Solid) wastes. Discharge of liquid wastes (and gaseous wastes) are authorized jointly by the Department of Environment and the Ministry of Agriculture, Fisheries and Food (MAFF) under the Radioactive Substances Act (1960). Authorizations for two power stations were received from the CEGB.

3.2.2 Treatment

The data provided by UKAEA indicates that the treatment of liquid waste streams is selective, based on gross activity of the various streams, selected critical population groups, and selected radionuclides.

Laundry wastes for example are filtered, whereas fuel element storage pond cooling water, and contaminated lubricating oil, are treated to varying degrees by filtration, (vacuum and pressure) ion exchange, and a series of further treatments which have specialty applications including;

- chemical precipitation
- evaporation
- solid/liquid separation by centrifuge
- hydro cyclone
- reverse osmosis
- lamella separation

No data was provided on the presence of suspended solids in these effluents before or after treatment.

A study of environmental radioactivity in Cumbria conducted by Wade, Eggleton, and Pierson summarizes experimental work done

since 1978 around the Sellafield (British Nuclear Fuels Ltd.) reprocessing plant. (Ref. 20)

The summary does not deal with nuclear power plant effluents but does provide an insight into the operative transfer and adsorption mechanisms for selected radionuclides to environmental particulate matter. This includes a sea to land transfer mechanism, involving attachment of radionuclides to suspended particulate matter, followed by wind transportation of these particles to the land where winds blow onshore. A mathematical model of the mechanism has been developed.

3.2.3 Utility

The CEGB responded with information including the authorizations for the Hinkley Point and Oldbury generating stations (1974 and 1967 respectively).

An interesting aspect of the authorizations is that liquid radioactive waste is defined as meaning "radioactive waste consisting of a liquid with or without solid matter in suspension therein".

The cover letter indicates that particulates in U.K. nuclear power station effluents are trivial, noting further that all effluents are filtered at a level of 5 micron and that resulting effluent discharges carry less than 2 parts per million (2ppm) particulate matter.

3.3 Japan

3.3.1 Regulatory Agency and Utility

Letters were written to the Japan Atomic Energy Commission (JAEC) and to eight Japanese nuclear power plant operators. JAEC did not respond but a substantial block of relevant data was received from a utility, the Japan Atomic Power Company. Due to a suspended solids incident in 1982 at the Tsuruga power station this utility undertook a special investigation which was completed in 1984. The investigation is so comprehensive as to warrant special mention and a summary of the data is included in Appendix B to this report.

While there was no official response from JAEC, the Japan Atomic Power Company provided some general details of regulatory control.

The following requirements apply to liquid and gaseous effluents;

1- Total evaluated annual dose to total body (whole body)(dose equivalent) to gonad or bone marrow from

radioactive noble gases and radioactive materials in liquid effluents is 5 mrem/site.

2- Total evaluated annual dose to thyroid (dose equivalent) from radioiodine isotopes in gaseous and liquid effluents is 15 mrem/site.

The utilities have apparently set as a target 1 Ci/year per reactor for liquid releases. This is generally achieved by most reactor operators. The dose to the public is estimated to be below 0.1 mrem/year.

3.3.2 Treatment

Two main streams of the Tsuruga power station are subject to treatment. Floor drains are collected, evaporated, demineralized (Ion exchange) and held in a sample tank before discharge. Laundry drains are collected in a sump prefiltered through polyurethane foam, charcoal absorbed and held in a sample tank before discharge.

3.3.3 Charactarization of Solids

Considerable detail is provided on the composition of these wastes both before and after treatment. The isotopic distribution, solid, liquid partitioning, size of suspended solid particles and mineral/organic distribution are described. The mineralogical composition of these solids is given along with the effectiveness of treatment controls for each mineral.

Additional background on the Tsuruga incident is available in the literature. (Ref. 19)

3.4 Federal Republic of Germany (West Germany)

3.4.1 Gesellschaft fur Reaktorsicherheit (GRS) mbH

Regulatory control of nuclear power facilities in Germany falls under the Nuclear Safety Standards Commission, with respect to liquid effluents. Specific requirements are contained in Section 46, Part 1 of the Radiological Protection Ordinance (10/76) detailed monitoring of liquid effluents is specified under the KTA 1504 Safety Standard.

Five discharges are identified as requiring to be monitored if radioactive discharges cannot be precluded on the basis of design and operation of the plant these are:

1 - Waste Water - Water collected in the discharge tank from the controlled access area.

2 - Service Cooling Water - Intermediate Cooling Water

3 - Turbine Building Waste Water - Drains

4 - Main Cooling Water - Turbine condenser cooling

5 - Main Water Discharge - cooling water from recooling facilities

3.4.2 Utility

No specific measures for monitoring of suspended solids content are given in KTA 1504, however a West German utility Badenwerk Aktiengesellschaft provided details of several treatment systems employed for the handling of waste water streams.

These include chemical precipitaton, filtering, and ion exchange.

The controlling parameter for determining the need for treatment appears to be numerically based on a specific activity of 1.9 E+7 Bq/m-3. When a waste water exceeds this value it must be treated and this includes removal of any suspended solids in the stream. The above treatment techniques are employed sequentially or in parallel until such time as the effluent reaches the prescribed level of activity.

In addition to the numerical activity limit, a series of integrated limits also apply over specified time periods.

While we were not able to find specific regulatory documents to support this, a paper by J. Schwibach (Ref. 18) of "Landerarbeitsgemeinschaft Wasser" a regulatory study group, states that the removal of suspended solids from waste water (presumably defined as having greater than 1.9 E+7 Bq/m-3 of activity) is a condition of discharge in the Federal Republic of Germany. (Guideline LAWA 11/76).

Detailed information on monitoring locations and alarm requirements as well as release quantities at most of West Germany's nuclear power plants are provided.

Little or no data could be found in the German utility or regulatory agency responses with respect to the quantity or characteristics of suspended solids in waste waters although the radionuclide distribution of discharges (after treatment) were given.

3.5 France

3.5.1 Electricite de France

One French utility and one regulatory agency were canvassed.

The regulatory agency did not respond, however the utility Electricite de France, replied with some information.

French regulations require filtration of all effluents directed to active waste holding tanks before discharge at the following levels:

Non recycled steam generator purges	- 25 micron
All other liquids	- 5.0 micron

Additional filtration is applied to different treatment or purification circuits of pressurized water reactors so as to contain radioactive suspended materials at or near their source and to protect the demineralizers and other treatment equipment (water treatment plant) as follows:

Volumetric control circuit	
Upstream of demineralizers	- 0.45 micron
Downstream of demineralizers	- 6.0 micron
	- 25.0 micron

The filtration downstream of demineralizers is for control and containment of resin fines.

3.6 Finland

3.6.1 Institute of Radiation Protection

Regulatory Guide YVL 7.1 of the Institute. dated June 23, 1976 was provided which contained;

(1) Act on Radiation Protection 174/57, 1/65

(2) Statute on Radiation Protection 328/75, 393/58 and 545/68

(3) Resolution 594/68 Ministry of Health and Social Welfare

3.6.2 Interpretation

(1) and (2) are general provisions on radiation protection. They define dose limits to the public and stipulate concentration limits at source as derived from dose limits.

(3) defines absolute numerical quantities of radionuclides which can be released from nuclear power plants. These are derived from individual and collective dose limits and are staged in accordance with the radio activity involved or period of release.

No reference is made in the guides to monitoring or control of particulates in liquid effluents.

3.6.3 Additional Data

A 1985 study by Ilus et al at Loviisa nuclear power plant provides a breakdown of neutralization tank effluent (top and bottom) into soluble and particulate fraction for 10 major gamma emitting radionuclides as well as minimum detectable activities (MDA) for each radionuclide. (Ref. 17)

A treatment scheme involving filtration to 0.45 micron and cationic/anionic treatment of the filtrate is presented, however, it is not clear whether the treatment is a requirement of regulations or simply the methodology for the particular experiment described. The latter is most likely. (Paper is in Finnish).

3.6.4 Utility

Two Finnish utilities were canvassed. No response was received from either.

3.7 India

3.7.1 India Department of Atomic Energy

The India Department of Atomic Energy, Safety Review Committee responded with the following information;

1 - Regulatory Philosophy in India is to filter radioactive liquid effluents from Nuclear Power plants using filters or 25 microns or less. Technical specifications for operation of Nuclear Power plants include this as a requirement.

2 - Quantitative analysis of the isotopic composition of liquid streams are made to ensure that limiting conditions for operation are adhered to.

No response was received from Indian utilities

3.8 Sweden

3.8.1 Swedish Nuclear Power Inspectorate (SKI)

The Swedish Nuclear Power Inspectorate (SKI) responded that they had forwarded our request to the National Radiation Protection Institute (NRPI) who have regulatory control over liquid (and gaseous) effluent releases.

General regulations are provided and these are expressed in terms of the resultant reduction of critical group dose equivalent and resulting global collective dose equivalent as follows; (10 Regulation SSI FS 1977:2);

> "Every nuclear power station shall have facilities for the retention of radioactive substances (e.g. filters, decontamination plant, collecting tanks) of such design that the sum of the weighted organ dose equivalents for the critical group due to expected resulting releases is less than 0.1 millisievert (10 millirems) per year and that the global collective dose equivalent is less than 5 mansieverts (500 manrems) per year per gigawatt installed electric power."

No reference is made to suspended solids.

Several Swedish utilities were polled, and one turned our request over to NRPI. However, no utilities responded directly.

3.9 ISRAEL

3.9.1 Israel Atomic Energy Commission

Releases of liquid radioactive wastes during routine and upset conditions is controlled by the licensing division of the Israel Atomic Energy Commission which provided draft requirements for gaseous and liquid waste discharges.

Limits of activity of liquid releases are set at 40 Ci/year for all isotopes other than Tritium and 2000 Ci/year for Tritium. No mention is made of suspended solids and the requirements for treatment of specific waste streams is based on ALARA with the monetary equivalent of unit dose set at $100/man rem.

No Israeli utilities were identified

3.10 Brazil

3.10.1 The Comissao Nacional de Energia Nuclear

The Comissao Nacional de Energia Nuclear responded that CNEN adopts USNRC Standard Technical Specifications (10CFR-20, (106) or equivalent) thus, CNEN's technical specifications do not include any requirements concerning liquid borne radioactive suspended solids. No response was received from Brazilian utilities

3.11 Mexico

3.11.1 Comision Nacional de Seguridad Nuclear y Salvaguardias

A response was received from the Mexican authority Comision Nacional de Seguridad Nuclear Y Salvaguardias. Liquid effluent control for the Laguna Verde Nuclear Power Project follows the US

Nuclear Regulatory Commission regulations specifically 10 CFR Part 20 (106). No response was received from the utility.

3.12 New Zealand

3.12.1 Department of Scientific and Industrial Research

A response from the New Zealand Department of Scientific and Industrial Research, Institute of Nuclear Sciences noted that the New Zealand government have abolished the Atomic Energy Committee.

3.13 South Africa

3.13.1 Regulatory Agency

A South African Regulatory agency could not be identified at the beginning of the project and therefore no letter was sent.

3.13.2 Utility

The utility, ESCOM - responded that they were unable to provide any technical information on the subject and suggested that Electricite de France might provide some data.

3.14 Peoples Republic of China

A response from the Institute of Atomic Energy in Peking provided general information with respect to the research being conducted by the Institute. It contained no information about the Chinese nuclear power program.

3.15 Switzerland

3.15.1 Swiss Federal Office of Public Health

The Swiss Federal Office of Public Health responded with a copy of a report of their 1984 Annual Surveillance Study for Radioactivity in Switzerland. (In German and French).

The report deals with all sources of natural and manmade radioactivity. Manmade radiation includes both occupational and public dose. The details of operational criteria and treatments applied for reduction of airborne or liquid waste discharges are not included.

Two Swiss utilities were polled put did not respond.

TABLE 6

Country	Regulatory Aspects	Studies of Suspended Radionuclides	Particle Size	Treatment Practise	Receiving Water
Brazil	Adopts US NRC Standards	No Data	No Data	U.S. Approach	Fresh
China Peoples Republic	No Data	No Data	No Data	No Data	No Data
Finland	No specific regulations for suspended solids	Yes-see page 17	No Data	Includes - Filtration - Ion exchange	Sea
France	Appear to have specific regulations for suspended solids	Yes - See Page 20	No Data	Includes: - Segregation - Filtration - Ion exchange	No Data
Germany Federal Republic	Appear to have Specific regulations for suspended solids	No Data	No Data	Includes - Precipitation - Filtration - Evaporation - Ion Exchange	Fresh
India	Regulatory "Philosophy" requires Filtration	No Data	No Data	Filtration to < 25 M	Sea
Ireland	No Power Plants	No Data	No Data	No Data	No Data
Israel	No specific regulations on suspended solids	No Data	No Data	No Data	No Data
Japan	No specific regulations on suspended solids	Yes - see Page 25	Yes-see Page 20	Includes: - Segregation - Filtration - Evaporation - Ion exchange - Charcoal Filtration	Sea
Mexico	Adopts US NRC Standards	No Data	No Data	US Approach	Sea
New Zealand	No Power Plants	No Data	No Data	No Data	No Data
South Africa	No Data	No Data	No Data	No Data	No Data
Sweden	No regulations specific to suspended solids	Yes See page 16	No Data	General Data only	No Data
Switzerland	No regulations specific for suspended solids	No Data	No Data	No Data	No Data
United Kingdom	No regulations specific for suspended solids	Yes See page 15	No Data	Includes: - Filtration - Ion exchange - Evaporation - Centrifugation - Reverse Osmosis	Sea
United States	No regulations specific for suspended solids	Yes See page 7	No Data	Includes: - Segregation - Filtration - Evaporation - Ion Exchange	Fresh/Sea

3.16 Ireland

3.16.1 Nuclear Energy Board of Ireland

The Nuclear Energy Board of Ireland responded that Ireland has no nuclear power stations and therefore, they are unable to provide any data.

4. Summary of Findings

4.1 Technical Information

4.1.1 Origin of Radioactive Suspended Solids

Depending on the type of nuclear reactor systems being employed, there exist fundamental differences between the types and quantities of liquid radioactive wastes generated which in turn affects the type of radioactive suspended solids found in these waste streams.

In a pressurized water reactor (PWR), the primary coolant does not mix with the steam used to drive the turbine. For this reason, the liquid wastes generated at PWR's generally have lower concentrations of radioactive materials than do boiling water reactors (BWR's). For a heavy water PWR such as the Candu system, this is further reduced by a number of design and operating features including the requirements to control losses of heavy water due to high cost and higher concentrations of tritium. In addition, failed fuel detection combined with on-line refuelling capability contribute to a reduced presence of fission products in the liquid waste streams of pressurized heavy water reactors, leaving mainly corrosion and activation products.

While all radioactive liquid waste streams contribute to the total inventory of suspended solids in the active liquid waste system, there is general concensus in the literature that two sources are the major contributors. These are:

1. The floor drain systems serving controlled areas,

2. The drains from laundry and decontamination areas.

A major unpublished study by a Japanese utility concentrated on these in 1984, (Appendix B) and concluded that these sources were most significant and that certain radionuclides exist partially in the insoluble or particulate state in the liquid waste storage tanks. (Ref. 2, 4)

Particulate radionuclides are largely activation or corrosion products, as well as Cesium and Cerium. Ten radionuclides have

been most extensively studied either by virtue of their presence or their importance to pathways analysis. They are the following;

1 Mn-54
2 Co-60
3 Fe-55
4 Cr-51
5 Cs-134
6 Cs-137
7 Zn-65
8 Nb-95
9 Zr-95
10 Ag-110m

Many other radionuclides have been studied of course, but the above tend to be associated with particulate matter more frequently than others in research reports.

An important finding with respect to the issue of sources of suspended radioactive solids is that many appear to be the result of attachment of soluble radionuclides to transient and otherwise inactive suspended solid particles present in the waste water prior to being discharged. The mechanisms and conditions for such attachments appear to be complex and not well understood. (Ref. 17, 21)

In addition, the ratio of soluble to particulate radionuclide can change immediately or soon after contact with the receiving water as shown in the following Table 7.

Other sources of particulate radionuclides include backwash water from demineralizer trains (Ref. 31) and contaminated resin fines from the same equipment. Activated corrosion products from structural materials have also been cited.

4.1.2 Quantities of Radioactive Suspended Solids

The international technical literature is highly variable with respect to the quantities of radioactive suspended solids contained in nuclear power plant liquid effluents.

As a percentage of total liquid waste volume, the quantities of suspended solids appear to be small because visible solids are filtered out and diverted to active solid waste disposal before the liquid waste is sent to the storage tanks. As a percentage of total activity, excluding Tritium, the amount which exists in the storage tanks as particulate can vary from 10% to 50% depending on the radionuclides present. (Ref. 4, 5) Complicating this further is the fact that depending on conditions present in the waste storage tanks, some radionuclides change from soluble to insoluble states over time. (Ref. 17) Some effluent substreams such as equipment drains have been shown to contain up to 100 parts per million (PPM) of particulates (Ref. 31).

Table 7 (Table XII, Ref. 15)

CHANGES IN PHYSICAL AND CHEMICAL FORM OF DISCHARGED RADIONUCLIDES WITH INCREASING DISTANCE FROM THEIR SOURCE

Recalculated from Nelson

NUCLIDE	LOCATION*	PER CENTAGE DISTRIBUTION				
		Particulate	Soluble			
			Total	Cationic	Anionic	Uncharged
^{65}Zn	Effluent	16	84	84	0	0
	A	51	49	47	0.5	1.5
	B	77	23	22.5	0.2	0.2
	C	84	16	15.5	0.3	0.2
	D	80	20	17	2.5	0.5
^{51}Cr	Effluent	2	98	3	94	1
	A	3	97	3	93	1
	B	7	93	3	86	3
	C	10	90	1	89	0
	D	10	90	1	89	0
^{60}Co	Effluent	5	95	1	93	0
	A	65	35	31	3	0.7
	B	63	37	34	1.5	2
	C	64	36	20	11	5
	D	68	32	26	1	5
^{46}Sc	Effluent	68	32	11	20	2
	A	77	23	3	19	1
	B	90	10	1.4	8	0.7
	C	88	12	3	7	2
	D	89	11	0.5	9	2
^{54}Mn	Effluent	3	97	94	2	0
	A	57	43	33	3	7
	B	70	30	28.5	0.5	1
	C	78	22	20	1.5	0.2
	D	70	30	14	13	3
^{124}Sb	Effluent	9	91	0	91	0
	A	5	95	1	40	54
	B	2	98	0	22	76
	C	2	98	2	23.5	72.5
	D	1	99	0	16	83

* Site A is nearest to the source. Site D is furthest from the source and nearest to the mouth of the Columbia River.

4.1.3 Nature of Radioactive Suspended Solids

In an extensive two year unpublished study at the Tsuruga nuclear power station, the Japan Atomic Power Co., investigated in detail the nature of suspended solids in laundry and floor drain wastes. A summary of their findings is included in Appendix B of this report.

The Tsuruga data provides a typical assessment of the radioactive contribution of the suspended solid components of the three major radionuclides found in laundry wastes, Mn-54, Co-60, and Cs-137. Clearly, Co-60 is a major contributor.

Other investigations, particularly the USEPA studies at Oyster Creek, confirm the significance of Co-60 and Mn-54 as insoluble sources of radioactivity. (Ref. 4, 17)

In the Tsuruga work, the particle size of suspended radioactive solids is addressed in detail as is the composition of floor drain and laundry waste solids. Two other Japanese papers (Ref. 31, 33) have examined particle size distribution in the substreams of equipment drains placing the mean particle size of suspended solids in these streams at 3 to 5 microns.

Considerable data is available on the radionuclide composition of these solids or more correctly on the solid/solution distribution of radionuclides present in the waste tanks. Holmberg, (Ref. 21) Preston, (Ref. 7) and Ilus, (Ref. 17) are referenced in a paper by Sjoblom and Ojala (Ref. 11).

> "According to Holmberg (Ref. 11) Co-60 and Mn-54 in Swedish conditions existed both in Cationic and particulate form in the waste water tanks of a nuclear power plant, and Ag-110m in anionic or particulate form. Preston showed that Co-60 and Mn-54 in liquid discharges from Bradwell power station were mostly in particulate form and Sb-124 in soluble form. The distribution of discharge contents into soluble and particulate form was studied by Ilus et al in connection with a discharge from a waste tank which had been stored for more than one year at the Loviisa power plant. Sb-124 was almost completely in soluble form Mn-54 in particulate form and Co-58, Co-60 and Ag-110m in both soluble and particulate form. After mixing with the sea water circuit Sb-124 was still in soluble form and Ag-110m in both soluble and particulate form."

4.1.4 Treatment for Removal of Radioactive Suspended Solids

Treatment methodologies for the removal of radioactive suspended solid materials in nuclear power plant effluents are referenced extensively in the international literature.

Segregation of liquid waste streams into high and low conductivity fractions and laundry wastes is nearly universal, due to the greater presence of solids in raw water compared to demineralized water and the presence of detergents in laundry wastes.

Filtration particularly for high conductivity wastes, and laundry wastes, is commonly applied, often in combination with evaporation, ion-exchange or adsorption.

In general, these techniques appear to be effective in reducing the overall impact of released suspended solids as evidenced in the USEPA work at Oyster Creek.

Other technologies for treatment of liquid wastes for removal of suspended solids include; chemical precipitation, centrifuging, hydrocyclones, reverse osmosis or lamella separation, all of which have specialty application. Some effort is being applied to the development of commercially applicable membrane filters in Japan (Ref. 31) and electomagnetic filtration is being studied in France and possibly the US and UK. Electromagnetic filtration is said to be particularly effective in removal of corrosion products (Ref. 32) Figurb 2 shows the experimental results of electromagnetic filtration.

Because of the preponderance of corrosion and activation product radionuclides in suspended solids, material changes in the plant can also have an effect on suspended radionuclides in the waste streams. Devell et al (Ref. 10) discuss this effect with respect to Swedish nuclear power plants;

> "Among beta emitters, Cr-51, C0-58, Co-60, Zn-65, Cs-134 and Cs-137 are found in the highest concentrations. Total releases of beta/gamma from the nuclear power plants reached a maximum during 1976-1977 but have decreased since then. At Oskarshamn for example, the decrease is due to improved removal of suspended material in the effluents, and replacement of brass tubes in the condenser with ones of titanium, which reduced the production of Zn-65."

Figure 3 (Ref. 4) presents a typical liquid radioactive waste treatment system for a U.S. BWR station commissioned in the late 1960's. Figure 4 shows a French PWR liquid treatment system for comparison.

Figure 4 (Ref. 4)

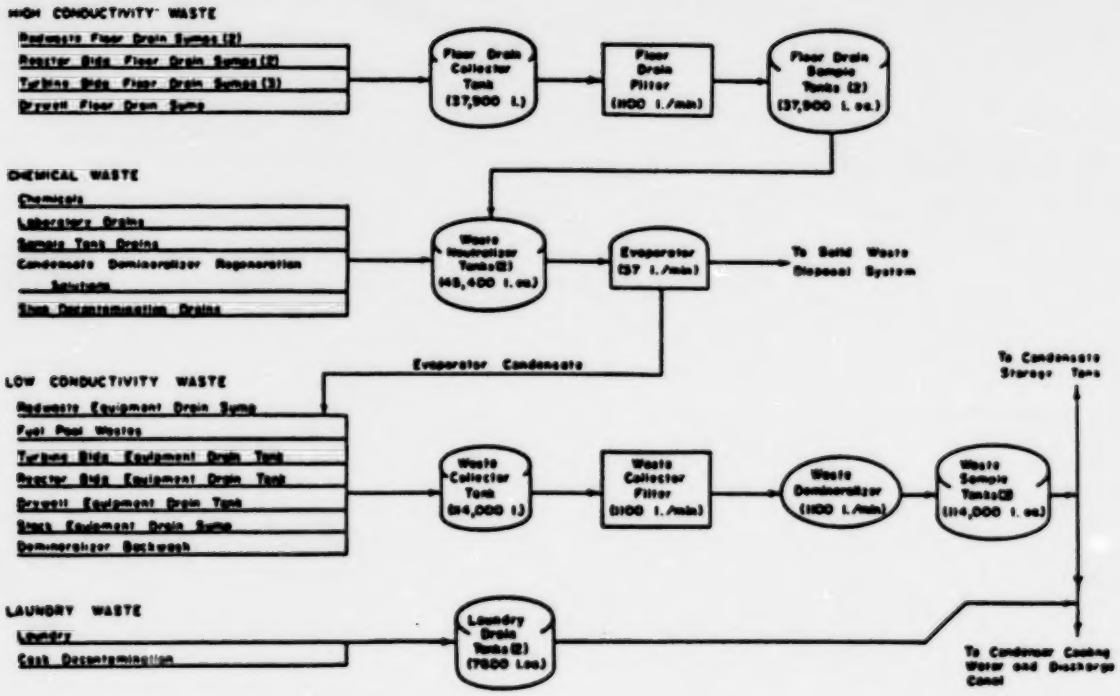
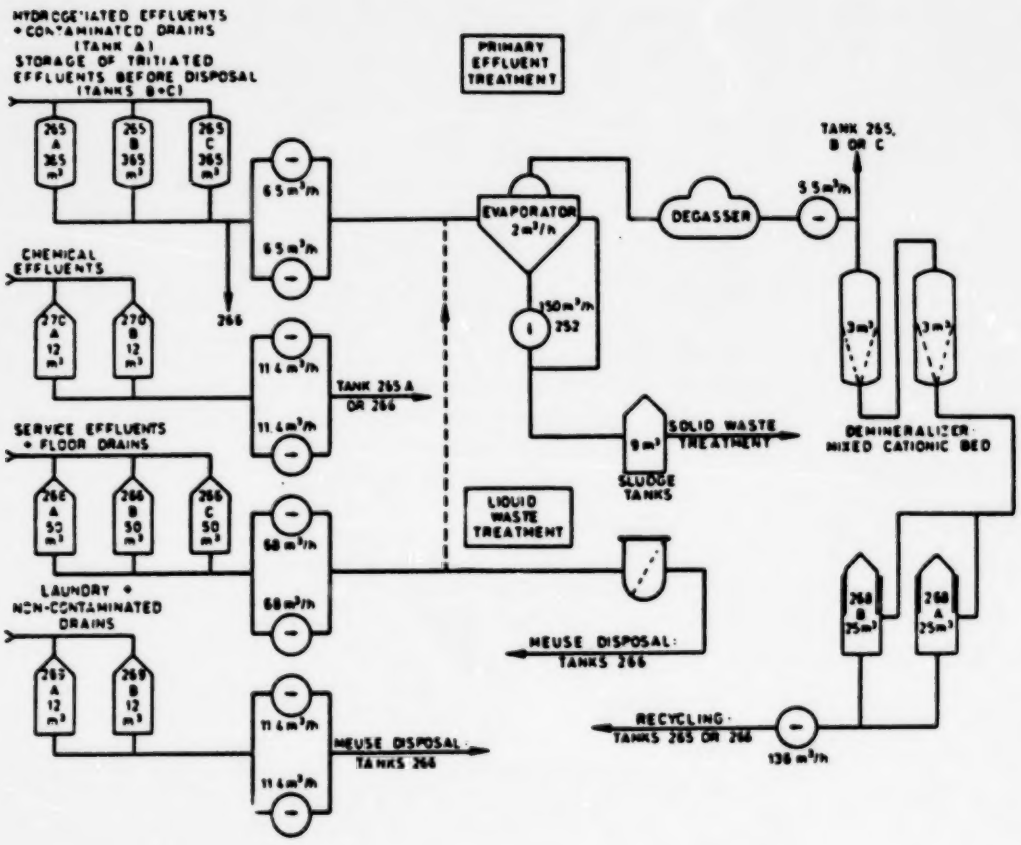

HIGH CONDUCTIVITY WASTE
Radwaste Floor Drain Sumps (2)
Reactor Bldg. Floor Drain Sumps (2)
Turbine Bldg. Floor Drain Sumps (3)
Drywell Floor Drain Sump
Floor Drain Collector Tank (37,900 l.)
Floor Drain Filter (1400 l./min)
Floor Drain Sample Tanks (2) (37,900 l. ea.)
CHEMICAL WASTE
Chemicals
Laboratory Drains
Sample Tank Drains
Condensate Demineralizer Regeneration Solutions
Steam Decontamination Drains
Waste Neutralizer Tanks (2) (45,400 l. ea.)
Evaporator (57 l./min)
To Solid Waste Disposal System
Evaporator Condensate
LOW CONDUCTIVITY WASTE
Radwaste Equipment Drain Sump
Fuel Pool Wastes
Turbine Bldg. Equipment Drain Tank
Reactor Bldg. Equipment Drain Tank
Drywell Equipment Drain Tank
Steam Equipment Drain Sump
Demineralizer Backwash
Waste Collector Tank (84,000 l.)
Waste Collector Filter (1100 l./min)
Waste Demineralizer (1100 l./min)
Waste Sample Tanks (2) (114,000 l. ea.)
To Condensate Storage Tank
LAUNDRY WASTE
Laundry
Cask Decontamination
Laundry Drain Tanks (2) (7500 l.ea.)
To Condenser Cooling Water and Discharge Canal

Figure 5 (Ref. 30)



Laundry wastes have proven to be one of the most difficult streams to control for suspended solids content primarily due to the foaming effect of detergent on evaporator operation. One utility has solved this problem through the use of course prefilters and charcoal adsorption beds.

4.1.5 The Fate of Released Radioactive Suspended Solids in the Environment

Primarily due to work conducted under regulatory agency sponsorship by various national and international research laboratories there is a large volume of published material on the fate of released radioactivity present in suspended solid form. Unfortunately, few general conclusions can be drawn from this work since it is site specific. The Radiological Surveillance studies conducted in the United States at four nuclear generating stations (Ref. 1, 2, 3, 4), and the work by Battelle Pacific Northwest Laboratory on the Columbia River jointly sponsored by USEPA and USNRC are good examples. (Ref. 15)

The IAEA's International Laboratory of Marine Radioactivity in Monaco, which is largely concerned with the measurement of long lived radionuclides in the marine environment, has conducted leading work on the fate of suspended solid radionuclides as has the Ministry of Agriculture, Fisheries and Food Laboratory at Lowestoft U.K.. A significant reference document exists in the 1985 Sandia National Laboratories Report, Sand-85-2631 "Compilation of Selected Marine Radioecological Data for the U.S. Subseabed Disposal Project: Summaries of Available Radioecological Concentration Factors and Biological Half Lives" by Gomez, Marietta and Jackson. (Ref. 23)

The initial fate of suspended solid radioactive materials in liquid effluent streams is largely to sediments. The extent to which these sedimented radionuclides are modified by the receiving water environment, assimilated by fish or plant life, or moved around on the river, lake or sea bottom, has been well studied in the literature on a site specific basis.

Since the radionuclides most commonly observed in suspended solids can exist partially in the particulate state, with the remainder in the soluble state, and, since this distribution can be affected by the receiving water, (pH, salinity, sediments or organic material) clearly the issue is complex.

In a lengthy and highly referenced paper to a 1973 IAEA Symposium on Environmental Behavior of Radionuclides Released in the Nuclear Industry, Fukai, and Murray of the IAEA Monaco Laboratory review the environmental behavior of radiocobalt and radiosilver released from operating reactors into a number of receiving waters in India, Italy, the U.K. and the U.S. (Ref. 24). They conclude;

> "These data indicate that, although the major sink for radiocobolt is bottom sediments, some fractions tend to recycle into a soluble phase and go through complicated processes such as hydrolysis, inorganic and organic complex formation, adsorption, desorption with suspended particles and bottom sediment etc. In the case of radiosilver, the complex formation with chloride ions in seawater medium seems to be important in maintaining this element in solution, while there is practically no data available for freshwater systems."

Among the particulate associated radionuclides referenced in the international literature, radiocobalt and radiocesium appear to have been extensively studied. (Ref. 20, 21, 22, 24, 26)

Pathways evaluation is also a complex situation and depends upon the particular receiving water, the suspended radionuclides present and numerous post-release interactions. Two studies examined the pathway from sediments to man via bottom feeding organisms such as oyster and mussel for radionuclides including Co-60, Zn-65, Mn-54, and Cs-137. (Ref. 25, 5)

In the literature reviewed, most of the pathway work has been done in relation to long-lived radionuclides around fuel reprocessing facilities or research establishments. An interesting but site specific suspended solids pathway exists at the Sellafield facility in the U.K. (Ref. 8) via wind-carried sea spray onto exposed shorelines.

The largest uncertainty with respect to pathways evaluation for suspended solid radionuclides is the complex physiochemical nature of these materials, referred to as "speciation" in many studies and research reports. (Ref. 27)

Many radionuclides, including those most frequently found in suspended solid form can, regardless of the degree of filtration or treatment applied before release, redistribute themselves between particulate and soluble state after being introduced to the receiving water. Some, particularly radiocesium, have a strong affinity for free particles in the receiving water and consequently attach themselves. Thus, new radioactive suspended solids are formed after release of the waste stream. This phenomena is well documented in the USEPA surveillance studies and in the Columbia River studies. (Ref. 2, 4, 15)

4.1.6 Summary of Technical Data

The origin of radioactive suspended solids in nuclear power plant liquid effluents is generally well documented in so far as specific waste streams have been identified, i.e. laundry wastes and floor drain wastes, demineralizer backwash and carry over of resin fines.

Except for isolated cases, the quantity and nature of these materials has not been examined in detail and is further complicated by diverse physical-chemical interaction both in the waste storage tanks and after release to the receiving water.

The fate of suspended solids has been extensively studied but appears to be site specific. More information is available related to long-lived radionuclides from fuel reprocessing than for activation and corrosion products normally associated with nuclear power plant releases.

4.2 Regulatory Aspects of Suspended Solids in Liquid Effluents

Although forty (40) letters were sent out to international regulatory agencies, only thirteen (13) countries responded. Through the literature search and direct telephone contacts, a further two (2) countries were added to this list.

Due to language difficulties or for lack of nuclear power data, four (4) regulatory agencies did not provide any useable information. Among the remaining eleven (11), three (3) including the U.S., adopt USNRC standards and these can be summarized as a group. The remaining eight (8) provided varying levels of regulatory detail and can be addressed in that order.

4.2.1 United States Nuclear Regulatory Commission

Control of radioactive liquid wastes in U.S. nuclear power stations is regulated through the Code of Federal Regulations 10-20, article 106, Chapter 1 (1982) (Appendix B). The regulations contain no provision for monitoring or control of suspended solids. USNRC Regulatory Guide 1.21 (Rev. 1), Section C-6 defines the need to thoroughly mix large volumes of liquid waste before sampling "to assure that any sediments or particulate solids are distributed uniformly in the waste mixture".

The regulatory agency takes the position that the complexity of post-release physical and chemical radionuclide interactions with the receiving water obviates the need for control or monitoring of these materials. Nonetheless, considerable filtration is normally practiced in U.S. nuclear power plants in order to meet the radionuclide specific activity limits set out in Table II of 10CFR-20, which indicates that a significant amount of liquid waste activity is present in the form of solid material.

4.2.2 Brazil and Mexico

The regulatory agencies of these countries, Comissao Nacional de Energia Nuclear (CNEN) of Brazil and Comision Nacional de

Seguridad Nuclear y Salvaguardias of Mexico each have adopted the USNRC standards.

4.2.3 Federal Republic of Germany

Control of the releases of liquid radioactive wastes in the Federal Republic of Germany appears to fall under several agencies. While the agency to whom our letter of inquiry was addressed did not respond directly, material received from several utilities and from the literature, suggest that suspended solids are controlled by regulations.

A paper presented to the IAEA in 1978 by J. Schwibach (Ref. 18), prepared by the Study Group on Radioactive Contamination of Surface Water, Federal Republic of Germany provides some insight into the regulatory philosophy with respect to suspended solids in Germany;

> "Radioactive effluents may only be discharged from discharge tanks. Suspended materials have to be removed by appropriate measures before discharge. Effluents may not be drained off by gravity, but have to be pumped out. Conduits have to be designed in such a way that circumvention of discharge tanks is excluded. While discharging effluents, water must not be conveyed to the discharge tank."

While a specific reference to the regulatory documentation supporting the above statement could not be identified, it is clear that the control authorities in the Federal Republic of Germany do address the issue of suspended solid materials in nuclear power plant effluents directly.

KTA Safety Standard 1504 (1978), provides details of measurement techniques for the monitoring of radioactive discharges. No reference to measurement of suspended solids content is made in this document.

4.2.4 Finland

Regulation of nuclear power plant liquid effluent discharges in Finland is provided by the Institute for Radiation Protection in Helsinki. Regulatory guide yvl 7.1, provides details of three (3) regulatory instruments: the Act on Radiation Protection 174/57. 1/65; the Statute on Radiation Protection, 328/75, 393/58 and 545/68,; and resolution 594/68 Ministry of Health and Social Welfare.

Numerical activity limits are provided, derived from collective dose limits. Action requirements based on multiples of this numerical limit are provided. No specific provisions are made for monitoring or control of suspended solids.

4.2.5 India

A response from the India Department of Atomic Energy Safety Review Committee indicated that the regulatory philosophy in this country is to require the filtering of radioactive liquid effluents from nuclear power plants using fitlers of 25 microns or less.

These provisions are stated to be included in the Technical specifications for the operation of nuclear power plants in India. No supporting documentation was provided with the response.

4.2.6 United Kingdom

Licensing of nuclear power plants in the U.K. is done under the Nuclear Installations Act. The Nuclear Installations Inspectorate have responsibility for the storage of radioactive solid wastes. Authorization of liquid effluent discharges is the joint responsibility of the Department of Environment and the Ministry of Agriculture, Fisheries and Food, under the Environment Department's Radioactive Substances Act (1960).

Effluents are filtered to 5 micron particle size and resulting effluent discharges carry less than 2 part per million (PPM) particulate matter.

4.2.7 Japan

No official response was obtained from the Japan Atomic Energy Commission (JAEC). Japan Atomic Power Co., provided some general aspects of regulatory liquid effluent control in that country.

A value of 1 Ci/year reactor is the release control target set by the utilities for liquid effluents to meet the requirements. No reference is made to specific control regulations or monitoring regulations for suspended solids in liquid effluents.

4.2.8 Israel

Releases of liquid radioactive wastes during routine and upset conditions is controlled by the licensing division of the Israel Atomic Energy Commission (IAEC). Draft regulations were provided by the IAEC. These set a limit on the activity of liquid radioactive waste discharge into the environment, of 40 Curies per annum (total) for all isotopes other than tritium and 2000 Curies per annum for tritium. Additional provisions are included but no reference is made to control or monitoring of suspended solids in liquid effluents.

4.2.9 Sweden

General conditions of regulatory control were provided by the National Radiation Protection Institute (NRPI);

> "Every nuclear power station shall have facilities for the retention of radioactive substances (e.g. filters, decontamination plant, collecting tanks) of such design that the sum of the weighted organ dose equivalents for the critical group due to expected resulting releases is less than 0.1 millisievett (10 millirems) and that the global collective dose equivalent is less that 5 mansieverts (500 manrems) per year per gigawatt installed electric power." (10 SSI FS 1977:2)

No reference is made to control or monitoring of suspended solids in liquid effleunts.

4.2.10 Switzerland

The Swiss Federal Office of Public Health responded to our inquiry with a copy of the 1984 Annual Surveillance Study for Radioactivity in Switzerland, which does not refer to operational power plant criteria for airborne or liquid releases.

4.2.11 France

While French regulatory agencies were not contacted directly, the utility reply indicates a regulatory limit on size of particles which can be forwarded to the waste storage tanks. No reference is made to limits on particles discharged to the receiving water.

4.2.12 Summary of Findings

While regulatory agencies in France, Germany and India appear to have some general provisions relating to control of radioactive suspended solids in liquid nuclear power plant effluents, very few, if any, specific regulatory control mechanisms exist among the twelve countries from which information is available.

The regulatory policy, in general, is directed to the control of the amount of radioactivity being released with liquid effluents and the resultant public dose.

In most cases the utilities must treat their liquid effluent streams to comply with the activity or dose limits and a common treatment practice is filtration. Thus, suspended solids removal is a means of achieving a reduction in the amount of radioactivity being released.

While utilities in some countries reported filtration requirements, we obtained no substantial information that these are indeed regulatory limits on discharges of suspended solids.

5. Conclusions

The major task for this project, was the international survey to obtain information from regulatory agencies and utilities concerning the presence and control of suspended solid material in the liquid effluent streams from nuclear power plants.

The overall conclusions of the survey can be summarized as follows;

1. The primary concern of both utilities and regulatory agencies is to control the amount of radioactivity released in liquid effluents and hence the public dose.

2. Active liquid waste treatment commonly involving filtration is widely practiced in nuclear power plants around the world. While the objective is reduction of total activity in the waste stream, the result is removal of suspended materials down to some particle size. Development of commercial scale membrane filters promises to reduce the size of material which can be practically removed from liquid wastes.

3. Limited information is available on the physical nature of suspended solid materials such as particle size and composition. The data which is available is process or stream specific.

4. The sources of radioactive suspended solids are mainly floor drains from controlled areas, and laundry wastes. In general, wastes which arise from decontamination activities where raw water (undemineralized water) is used for cleaning, tend to carry greater suspended solid loads. Other sources include demineralizer backwash and ion exchange resin fines.

5. Corrosion and activation products are the major contributors to the radionuclide content of suspended solids. Cobalt-60 and Manganese-54 are referred to more frequently than other radionuclides in the published and unpublished literature.

6. The environmental dispersion of solid and liquid radioactive materials differ markedly. Nevertheless, the removal of

suspended solid material from the waste effluent does not provide assurance that the radioactivity will be dispersed as a liquid. A substantial amount can attach itself to solids present in the receiving water or undergo other changes in physical-chemical form and thus be dispersed as a solid.

7. Suspended solid radioactive materials discharged along with liquid effluents will eventually find their way to the sediments. From here the radioactivity can follow a pathway through benthic animals or shoreline sediments to man. No general conclusions can be made with respect to the significance of these pathways since they are specific to the site and conditions of release.

6. Recommendations

6.1 Methodology

The survey methodology employed for this project included two approaches;

(1) A letter survey of utilities and regulatory agencies around the world.

(2) A literature survey to obtain published information concerning international practice.

The letter survey resulted in only 20 responses to 163 inquiries sent. Only one reply was received from 56 letters sent to U.S. utilities. The literature survey provided much more information, however, it was general in nature requiring more evaluation time to extract the relevant data.

It has been suggested that the poor rate of return to the letter survey, might be improved in future international surveys by providing additional detail on the client agency. This might be achieved by enclosing an information package or annual report of the Atomic Energy Control Board, to support the validity of the request for information. Alternatively the letters might be sent over an authorized signature on AECB letterhead.

It is also recommended that in future surveys of this kind, the literature survey be carried out first, in order to provide a basis for letters of inquiry. This should result in a smaller and more concentrated letter survey which could be followed up by telephone contact.

6.2 Future Work

In conducting the foregoing survey it became apparent that the subject of suspended solids in liquid nuclear power plant effluents is approachable from several viewpoints. The origin, characteristics and treatment techniques for example have been studied by the utilities since they are concerned with the quality of their discharges. The fate, environmental transfer and pathways to man for these materials tend to be more the domain of the regulatory agencies and the work is often carried out by national or international laboratories or research groups. The present study has taken a wide approach and it is clear that for any given subject area, considerably more published and unpublished material exists than could be reviewed within the present scope.

This study has examined the international non-Canadian literature related to suspended solids in nuclear power plant liquid effluents, and its findings may or may not be applicable to the Canadian nuclear power technology. The following recommendations are made for future work:

(1) It is recommended that the results of this survey be reconciled with available Canadian data and practice with respect to suspended solids in liquid effluents.

(2) It is recommended that additional work be undertaken to establish the technical basis of the regulatory approach to suspended solids by international authorities since the treatment practice appears inconsistent with the stated regulatory policy.

(3) It is recommended that further analysis be undertaken of the pathways to man for particulate associated radionuclides in liquid effluents. This might include the examination of pathways evaluations where conditions match those around Canadian power stations.

7. References

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